Balance and gait stability following sports-related concussion

Ann Sunderland
Fourth Year Medicine (Postgraduate)
University of Notre Dame, Sydney

Ann completed a Bachelor of Medical Science at the University of Wollongong in 2006. In 2007 she undertook an Honours project at the University of Canberra, whilst completing an apprenticeship in fitness.

Background: Concussion is an injury that is associated with many sports, in particular ice hockey, martial arts and the various codes of football. Concussion alters the stability of a person and as stability is vital when playing sports, the consequences of undiagnosed and untreated concussions are enormous. **Aim:** To look at various methods used to assess posture and stability in athletes, and their use in making safe return to play decisions after a sport-induced concussion. **Methods:** A search was conducted through PubMed, using the terms 'concussion' and 'sport.' Article titles were initially screened by the author and if the title seemed to be relevant to the purpose of the review, the abstract of the article was then screened for relevance. **Results:** Concussion negatively impacts upon an athlete's cognitive and motor functioning. Cognitive testing has previously been assessed and is currently used; however it has been shown that cognitive function may return before motor functioning. The time taken to recover the motor component is usually between three to ten days; however, this varies considerably between athletes. Balance and gait testing are a means of objectively assessing the stability of an athlete and have proved to be particularly useful in monitoring the recovery of an athlete after suffering concussion. **Conclusion:** Balance and gait testing are means of objectively assessing the stability of an athlete. Although their use is applicable to many situations, they have proved to be of particular usefulness in monitoring the recovery of an athlete after suffering concussion. Through their use, the subjectivity of the assessment is being eliminated, ensuring informed and supported decision-making regarding the safe return to play.

Introduction

Concussion is an injury that is associated with many sports, in particular boxing, football, ice hockey and martial arts. [1] According to Powell, [1] concussion is a 'trauma-induced alteration in mental status that may or may not involve a loss of consciousness.' Tommasone and Valovich McLeod [2] state that concussion is 'a mild brain injury resulting from a direct blow to the head resulting in physiological changes in brain function.' Guskiewicz *et al.* [3] defined concussion as 'an injury to the brain caused by a sudden acceleration or deceleration of the head that resulted in immediate, but temporary, alteration in brain functions, such as loss of consciousness, blurred vision, dizziness, amnesia or memory impairment.'

Various authors have stated that concussion causes a complex cascade of ionic, metabolic and physiological events that may adversely affect cerebral function for several days to weeks. [4,5] This leads to mitochondrial dysfunction, diminished cerebral glucose metabolism, reduced cerebral blood flow and altered neurotransmission, and ultimately results in the clinical presentation of neurological deficits, cognitive impairment and somatic symptoms. [5]

It has been shown that neuroimaging, such as computed tomography (CT) and magnetic resonance imaging (MRI), is often of little use in assessing less severe head injuries such as cerebral concussion, as such injuries tend to be functional rather than structural. [6]

Importance

Recently there has been increased awareness surrounding concussion and its associated negative effects due to the media coverage of several

high-profile athletes who have attributed their retirement to repetitive concussions. [1,7] After one traumatic brain injury, the risk of a second is three times greater, and after the second injury the risk of a third increases by a factor of eight. [8,9]

One of the most challenging issues facing practitioners when dealing with concussion is making the initial diagnosis. [1,10,11] The signs and symptoms present can differ considerably between individuals. [1] A survey conducted by Ferrara *et al.* [12] found that 33.0% of athletic trainers rely upon clinical examination and 15.3% on a symptom checklist in their evaluation of concussion. Additionally, 83.5% of those surveyed stated that the use of a standardised method of concussion assessment provided more information than routine clinical and physical examination alone. [12]

The possible consequences following a concussion are serious and potentially fatal. [13] Cantu [10] discusses the Second Impact Syndrome (SIS), which occurs when an athlete who has sustained an initial head injury, most often a concussion, sustains a second head injury before symptoms associated with the first have completely resolved. It is believed that this can cause cerebral oedema leading to herniation of the brain, ultimately proving to be fatal. [10] Other consequences of concussion, such as other head or bodily injuries, may be the result of having a slow reaction time and instability.

It is critical that functional and cognitive impairment are properly identified to prevent the risk of re-injury and to minimise further complications. [14] The rate of recovery is highly individual and as a result there is no standard guideline to use when determining when a person is fit to return to play. [5,14] At present it is through the use of cognitive testing and highly subjective motor control assessment that these important return to play decisions are being made.

Methods used to assess deficit

Neuropsychological testing is a common method used to assess when a person's cognitive function has returned to pre-concussion levels. A widely used and validated test of cognitive function is the Digit Substitution Symbol Test. [15] Other commonly used tests are the Hopkins Verbal Learning Test and the Stroop Test. [3,15-16] Randolph *et al.*, [18] in investigating the use of neuropsychological testing in the management of sport-related concussion, concluded that although the theoretic rationale for use of such tests is sound, they lack sensitivity and do not meet the necessary criteria to support a clinical application. [18] Although shown to be of value in concussion evaluation, they should not be used as the sole basis of a return to play decision. [19]

There is evidence that the return of motor function is independent of the return of cognitive function and tests of motor function take a longer time to return to normal after a concussion, than cognitive tests. [20,21] It has also been found that injured athletes do not display significantly poorer performance than uninjured controls on any of the neuropsychological tests, suggesting that the tests used are not sensitive enough to reveal cognitive deficits. [16] This was further demonstrated in a later study by Guskiewicz which concluded that differences in the neurocognitive scores between injured subjects and uninjured controls did not differ as significantly as differences in balance. [22] Despite this, neuropsychological testing is being used to determine recovery after a concussion and many important decisions surrounding return to play are being made based upon this information.

At present the only methods of determining the return of motor control are subjective, relying primarily on the discretion of the practitioner. Physical signs of concussion include poor coordination, gait unsteadiness and loss of balance. [19] Numerous studies have investigated possible methods of objectively assessing the return of motor control by looking at gait and stability. [3,5,8,9,14,16,17,20,21-27] The rationale behind the use of such testing is that the areas of the brain which are disrupted as a result of concussion are those that are responsible for the maintenance of postural equilibrium. [3]

Stability is the ability to maintain a desired postural orientation in response to perturbations generated from either internal or external sources. [26] Balance is the process of maintaining the center of gravity (COG) within the body's base of support. [20] Postural instability has been identified in various pathologic conditions such as traumatic brain injury, craniocerebral injury and cerebellar atrophy. [20] It is believed that communication between the visual, somatosensory and vestibular systems is lost in the majority of these individuals, causing moderate-to-severe postural instability in either the anterior–posterior direction, medial–lateral direction or both. [20]

Concussed individuals have been shown to adopt a more conservative gait strategy to maintain stability. [14,25] It has been found that stride length decreases and stride rate increases when stability is impaired. [8,21,24] Furthermore, sway from the centre of mass, in the medial-lateral direction, is increased after a concussion. [23-25]

The research methods previously used have been complex and in a laboratory setting, generally with the use of camera analysis systems and force plates which measure the ground reaction forces. [23-27] Although these methods are effective in assessing the balance deficit they are impractical for use during game play. It is essential that testing be conducted immediately after injury to increase the accuracy with which the practitioner can assess concussion in the acute phase. [11] As yet no valid and reliable field-based procedure has been presented to quantify the deficits of concussion on motor performance.

Many studies have further investigated the assessment of postural control by introducing challenges. Altered visual cues, obstacles and divided attention are the most common methods. [13,17,24]

It has been hypothesised that by removing visual cues, the balance deficit is increased. [17] Guskiewicz *et al.* [3] believe that the overall postural stability deficit can best be explained by a sensory interaction problem. They state that this inability prevents concussed athletes from accurately using and exchanging sensory information from the visual, vestibular and somatosensory systems. [3,22] As the integration of this information is essential for the maintenance of equilibrium, postural instability is seen in concussed athletes. They found that postural instability was greatest during difficult visual conditions, or when vision was removed altogether. [3]

With the introduction of an obstacle it was found that in concussed individuals a greater postural sway was seen, the peak sway velocities were faster and the time taken to complete a stride was also significantly greater. [13,25] Chou *et al.* [8] found that the walking speed for all subjects decreased with the introduction of an obstacle; however, no differences were seen between the concussed and normal groups.

Divided attention is achieved through dual tasking. Concussed individuals display signs of instability when attention is divided. [24,25] Catena *et al.* [25] concluded that this task was most sensitive in distinguishing between the injured and uninjured controls. The subjects are asked to perform a walking or standing task whilst simultaneously undertaking other activities. Van Donkelaar *et al.* [13] found that an individual suffering from a concussion may appear normal when attempting activities in isolation yet display noticeable deficits when performing two or more tasks simultaneously. Responding to questions, performing mental tasks (such as counting down from 100 in multiples of seven) and responding to noises by pressing a handheld trigger are examples of dual tasks.

Some researchers have found that the range of motion in the medio-lateral direction in the concussed subjects was greater during dual tasking when compared to the control group. [14,24] This was further supported by a later study conducted by Parker *et al.* [21] which found that injured subjects had greater sway and sway velocity than controls when their attention was divided through the performance of simple mental tasks. Stride patterns were also found to be significantly different in the concussed groups, with an increase in the time taken to complete a stride. [25]

As a means of determining variations in postural control some studies used baselines which were obtained at the beginning of the season, prior to injury. [3,17,28] This enabled comparisons to be made on an individual basis and allowed for variations within the population. Other studies were done retrospectively with the balance deficit being monitored until it returned back to what was believed to be normal. [26] Most studies did this with the use of matched controls. [21-25]

Duration of deficit after a concussion

The time taken for balance deficits to return to pre-injury levels is one that is debated. Most studies have concluded that a concussed athlete has returned to normal within three to ten days post injury. [22,26,27]. Parker *et al.* [21] found that even athletes suffering from a mild head injury, such as concussion, had several aspects of gait stability compromised for up to four weeks after the injury. To determine this, the investigators tested athletes usually within 24 hours of injury, again on day two or three and on at least one other occasion within the next two weeks [17,22,27]. The most significant alterations in gait and stability have been found in the first three days after concussion. For athletes that have a suffered a more severe head trauma the time taken to return to normal is greatly extended, with balance deficits still being seen at least two years later. [8,9,13]

Conclusion

Balance and gait testing are means of objectively assessing the stability of an athlete. Although their use is applicable to many situations, they have proved to be of particular usefulness in monitoring the recovery of an athlete after suffering concussion. Through their use, the subjectivity of the assessment is being eliminated, ensuring informed and supported decision-making regarding the safe return to play.

Recommendations

Concussion needs to be diagnosed, and recognised as an injury with potentially severe consequences.

- As response and recovery times are largely individual, sport participants should be assessed pre-season so as to obtain baseline data and at random times throughout the playing season.
- Sport participants should undergo thorough testing after suffering a concussion to assist in appropriate diagnosis and assessment of severity.
- Although clinical examination has an important role, it should be used as an adjunct to a more objective assessment.
- Return to play should not occur until a patient no longer has a deficit, as the risk of re-injury is significant.

Acknowledgements

This publication is a modification of a section from an Honours project in which Ms Patti Denham-Mason was the primary supervisor. Dr Warren McDonald acted as a secondary supervisor, and further assisted in the recruitment of subjects for data collection.

References

[1] Powell J. Cerebral concussion: Causes, effects and risks in sport. J Athl Train 2001;36(3):307-11.
[2] Tommasone B, Valovich Mcleod T. Contact sport concussion incidence. J Athl Train 2006;41(4):470-2.
[3] Guskiewicz K, Ross S, Marshall S. Postural stability and neuropsychological deficits after concussion in collegiate athletes. J Athl Train 2001;36(3):263-73.
[4] Byard R, Vink R. The second impact syndrome. Forensic Sci Med Pathol 2009;5(1):36-8.
[5] McCrea M, Guskiewicz K, Marshall S, Barr W, Randolph C, Cantu R, *et al.* Acute effects and recovery time following concussion in collegiate football players; The NCAA concussion study. JAMA 2003;290(19):2556-63.
[6] McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, Molley M, *et al.* Consensus statement on concussion in sport – The 3rd International Conference on concussion in sport, held in Zurich, November 2008. J Clin Neurosci 2009;16:755-63.
[7] Guskiewicz K. The concussion puzzle: 5 compelling questions. J Athl Train 2001;36(3):225-6.
[8] Chou L, Kaufman K, Walker-Rabatin A, Brey R, Basford, J. Dynamic instability during obstacle crossing following traumatic brain injury. Gait Posture 2004;20:245-54.
[9] Kaufman K, Brey R, Chou L, Rabatin A, Brown A, Basford J. Comparison of subjective and objective measurements of balance disorders following traumatic brain injury. Med Eng Phys 2006;28:234-9.
[10] Cantu R. Second-impact syndrome. Clin Sports Med 1998;17:37–44.
[11] Kissick J, Johnston K. Return to play after concussion; principles and practice. Clin J Sports Med 2005;15(6):426-31.
[12] Ferrara M, McCrea M, Peterson C, Guskiewicz K. A survey of practice patterns in concussion assessment and management. J Athl Train 2001;39(2):145-52.
[13] Van Donkelaar P, Osternig L, Chou L. Attentional and biomechanical deficits interact after mild traumatic brain injury. Exerc Sport Sci Rev 2006;34(2):77-82.
[14] Parker T, Osternig L, Lee H, Van Donkelaar P, Chou L. The effect of divided attention on gait stability following concussion. Clin Biomech 2005;20(4):389-95.
[15] Guskiewicz K, Bruce S, Cantu R, Ferrara M, Kelly J, Mccrea M, *et al.* National Athletic Trainers' Association position statement: management of sport-related concussion. J Athl Train 2004;39(3):280-97.
[16] Guskiewicz K, Riemann B, Perrin D, Nashner L. Alternative approaches to the assessment of mild head injury in athletes. Med Sci Sports Exerc 1997;29(7):213-21.
[17] Peterson C, Ferrara M, Mrazik M, Piland S, Elliott R. Evaluation of neuropsychological domain scores and postural stability following cerebral concussion in sports. Clin J Sports Med 2003;13(4):230-7.
[18] Randolph C, McCrea M, Barr W. Is neuropsychological testing useful in the management of sport related concussion? J Athl Train 2005;40(3):139-54.
[19] McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, Dvorak J, *et al.* Summary and agreement statement of the 2nd international conference on concussion in sport, Prague, 2004. Clin J Sports Med 2005;15(2):48-55.
[20] Guskiewicz K. Postural stability assessment following concussion: One piece of the puzzle. Clin J Sports Med 2001;11:182-9.
[21] Parker T, Osternig L, Van Donkelaar P, Chou L. Gait stability following concussion. Med Sci Sports Exerc 2006;38(6):1032-40.
[22] Guskiewicz K, Perrin D, Gansneder B. Effect of mild head injury on postural stability in athletes. J Athl Train 1996;31:300-6.
[23] Basford J, Chou L, Kaufman K, Brey R, Walker A, Malec J, *et al.* An assessment of gait and balance deficits following traumatic brain injury. Arch Phys Med Rehabil 2003;84:343-9.
[24] Catena R, Van Donkelaar P, Chou L. Cognitive task effects on gait stability following concussion. Exp Brain Res 2007;176(1):23-31.
[25] Catena R, Van Donkelaar P, Chou L. Altered balance control following concussion is better detected with an attention test during gait. Gait Posture 2007;25(3):406-11.
[26] Cavanaugh J, Guskiewicz K, Giuliani C, Marshall S, Mercer V, Stergiou N. Recovery of postural control after cerebral concussion: New insights using approximate entropy. J Athl Train 2006;41(3):305-16.
[27] Riemann B, Guskiewicz K. Effects of mild head injury on postural stability as measured through clinical balance testing. J Athl Train 2000;35(1):19-25.
[28] Oliaro S, Anderson S, Hooker D. Management of cerebral concussion in sports: the athletic trainer's perspective. J Athl Train 2001;36(3):257-62.

Conflict of interest

None declared.

Correspondence

A Sunderland: anniesunderland@yahoo.com.au